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Assessment of mangrove management alternatives in village-fringe forests of Indian Sunderbans: resilient initiatives or short-term nature exploitations?

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Abstract The village-fringe mangroves throughout the Indian Sunderbans have become ecologically fragile due to decades of unsustainable utilization practices and changes in hydro-geomorphic conditions. These mangroves are generally managed by the state-run Forest Department, community institutions and non-governmental organizations either separately or in collaboration. This paper attempts to assess the forest health of three such mangrove sites managed by these different institutions using quantitative vegetation surveys. Transformations of land use and land cover patterns of these sites from 2003 to 2013 have also been analyzed by geospatial techniques. Moreover, a qualitative estimation of the products and services provided by these mangroves was performed through participatory appraisals among the local forest dependents to comprehend the level of economic sustenance achieved. Results indicate that the overall performance of the site managed by a non-governmental organization in collaboration with local forest dependents was better than the other two sites managed by Forest Department and joint state-community institution respectively. Proper recognition of the causes of forest degradation and subsequent creation of zonal plantations with respect to species associations and utilization patterns were identified as the prime determinants of comparative success of the former site. Restructuring of community institutions by strengthening participation of actual forest dependents in decision making was suggested to be beneficial for mangrove restoration of sites performing poorly. In general, adaptation of collaborative approaches towards addressing the issues of tenure rights, legitimate sharing of mangrove produces and services, conflict resolutions among and within these institutions were found to be imperative for resilient management of these mangroves.

Keywords Community institution · Ecosystem services · Forest health · Non-governmental organization · State forestry · Sustainable mangrove management

Introduction

The mangroves of Sunderbans are considered as the world's largest contiguous mangrove forest spreading over an area of 26,000 km^2 across Bangladesh and India (Chaudhuri and Choudhury 1994). It was declared as a World Heritage Site by IUCN in 1987 and Biosphere Reserve by UNESCO in 1989. The Indian part of Sunderbans consists of about 106 deltaic islands with a maze of innumerable rivers, rivulets and creeks (Gopal and Chauhan 2006). Continuous

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diversion of land from mangrove to other land uses, mainly agriculture, shrimp ponds, habitation and consequential deforestation from 18th Century onwards led the forest area dwindle gradually (Datta et al. 2010). At present, about 4263 km^2 area of the Indian part is under mangrove cover although considerable discrepancies exist in the estimation of actual forest cover done by different governmental and international organizations (IUCN 1989; Mitra et al. 2011; Ray et al. 2011). The magnitude of change is higher in the buffer and transition zones of the Sunderbans, where forest dynamics are frequently disturbed by the local village communities due to their unsustainable livelihood practices (WBFD 2014). Consequently, Sunderbans has been affected immensely by quasi-natural hazards like cyclones, floods, storm surge, and riverbank erosion for centuries (Bhattacharya 1998). In order to achieve the sustained productivity of natural resources through proper management regimes, both state controlled and community based mangrove management programmes, known as Joint Forest Management (JFM), are being carried out in the Sunderbans since the last few decades under the supervision of state-run Forest Department (FD). Recently, some non-governmental organizations (NGOs) have also initiated wide spread plantation programmes of mangroves, especially after the devastations caused by the cyclone *Aila* in these areas on May 25, 2009 (Chattopadhyay 2009). Till now, mixed outcomes of success and failure have been experienced for all these different types of initiatives (Bhatt et al. 2011; Selvam et al. 2012). It was realized that the probable success of these programmes were often dependent on the complex mechanisms of community–environment interactions concurrently intersecting, overlapping and cutting across the apparently uncorrelated realms of ecological, economic, and socio-cultural sustainability in these remote parts of Sunderbans (Datta et al. 2012). In the present study, an attempt has been made to evaluate the status of sustainability and resilience of three such mangrove forest sites in Indian Sunderbans managed by different institutions viz. State FD, village level JFM committee, and NGO led village community respectively. The basic objective of the study was to examine the effectiveness of these different management regimes in mangrove conservation and plantation as well as to identify the best practiced site in terms of building resilience against environmental vulnerabilities.

Materials and methods

The methods applied in this study include delineation of study sites, ecological studies for assessing mangrove condition, geospatial analyses of forest cover dynamics and evaluation of economic sustenance.

Study sites

The present study sites are located in the north-eastern parts of the Indian Sunderbans within the Gosaba Community Development Block. More than a half a million people live in these forest-fringe environments exerting pressure on the mangroves for extraction of resources (WBFD 2014). However, this area still has considerable mangrove cover. This is largely due to the protection and surveillance by the FD for being a part of the Biosphere Reserve on the one hand and the Eco Development Committees (EDCs) functioning under JFM programme on the other. Information regarding the study sites and their respective management practices were derived from the author's a priori knowledge and field experiences in this region since last 12 years; personal interactions with government officials, mangrove ecologists, and NGO volunteers; and hitherto published literature.

Among the three forest sites selected here, the first one is a 20 years old plantation (22°8′22″N, 88°45′36″E) managed by the Bijoynagar EDC (Fig. 1). The prime characteristics of EDCs are that they were not legally entitled to extract mangrove resources from the managed areas at the time of their inception since their locations are adjacent to the wildlife sanctuaries of Indian Sunderbans. In fact, these EDCs are supposed to create healthy buffer forests around the sanctuaries as well as generate alternative livelihood options for the locals by strengthening intra-village development activities (e.g. poultry, duckery, freshwater fishery, embankment protection, orchard creation, ecotourism etc.). The Bijoynagar EDC was formed in 1998 with a protected forest area of 680 ha (WBFD 2014). Back then, the entire Sunderbans were suffering from acute absence of alternative fuel sources (e.g. coal, LPG, solar). The Bijoynagar area, not being an exception, experienced widespread deforestation due to rampant wood pilferage and expansion of shrimp aquaculture farms. In such circumstances, the EDC started to raise new mangrove plantations with primary emphasis on
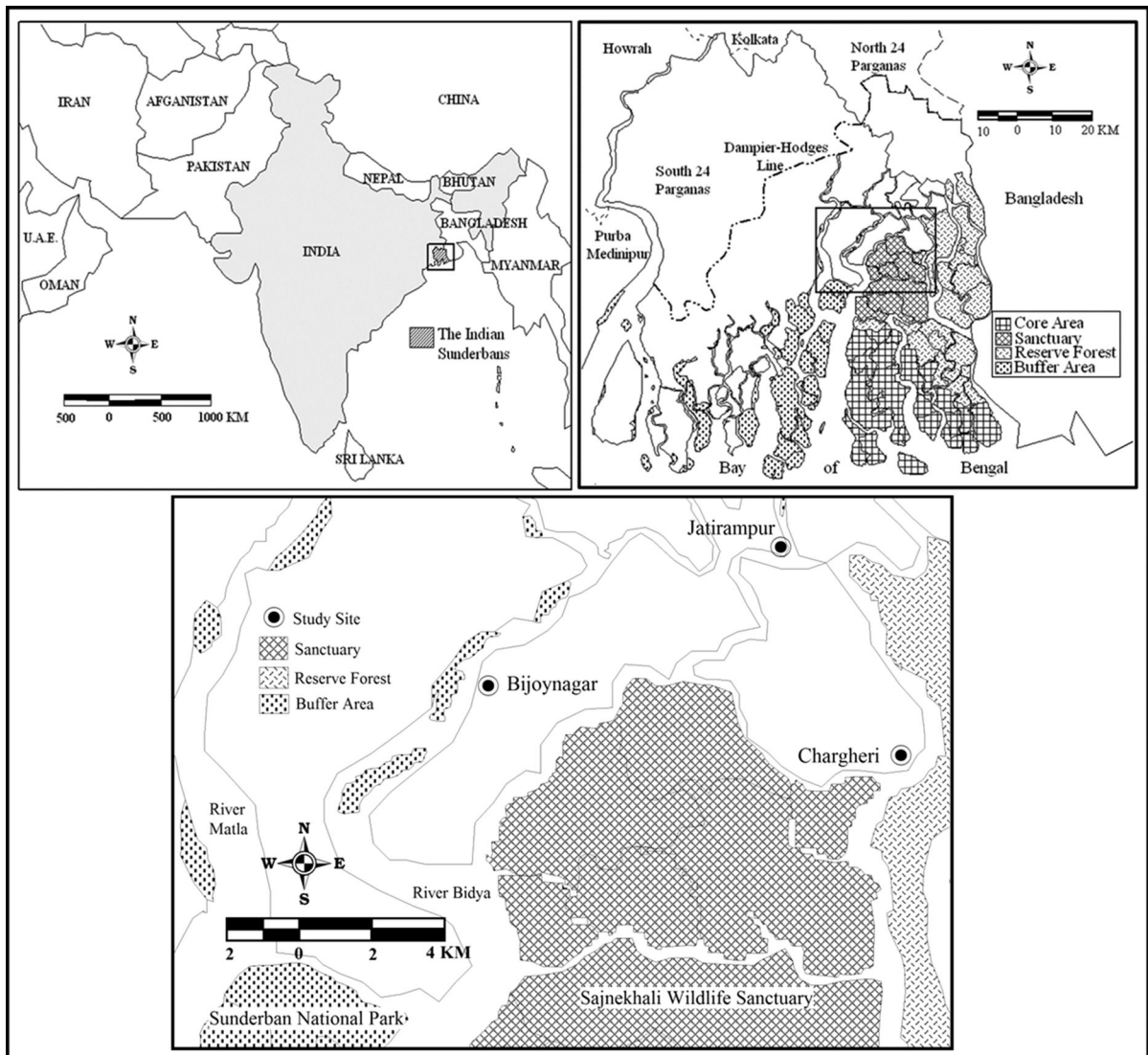
Fig. 1 Location map of the study sites

few species like *Avicennia marina*, *Ceriops tagal* (lower grounds) and *Excoecaria agallocha* (higher grounds) on a deforested riverbank comprised of *Porteresia coarctata* grass and stumps of already logged trees. Over the years, EDCs had legally provisioned the controlled extraction of some non-timber forest products (NTFPs) like mangrove edibles, honey and wax for the betterment of livelihood quality of their members. However, all these socio-economically advantageous endeavours had not always ensured the expected ecological benefits as many of the EDCs were reported with partial or complete absence of regular forest management activities viz.

fencing, propagule sheltering, abiotic litter clearing etc. (Datta et al. 2010). The present study aims to explore these aspects of Bijoynagar EDC's functional status and consequent outcomes in detail.

The second site is a newly formed estuarine mudflat known as *Jatirampur Chara* (22°9′4″N, 88°51′2″E) and protected by the FD. According to the local villagers, most parts of this mudflat emerged fully from the River *Dattar Gang* in the late 1980s. It is only in the mid-1990s that the mudflat became vegetated with mangrove species like *Porteresia coarctata*, *Avicennia marina*, *Bruguiera gymnorhiza* (outer parts), *Nypa fruticans* and *Xylocarpus granatum* (inner

parts). In the later years, other species might have established themselves on the mudflat through ecological succession. For example, *Aegialites rotundifolia* had spread around the mudflat (in the brackish water zones) between the high tide level (HTL) and low tide level (LTL). Since this was designated as a vested land, the FD legitimately became the custodian of this forest. Accordingly, all types of logging activities were legally prohibited here akin to other FD protected zones of Indian Sunderbans. The local forest guards and villagers revealed that the FD had not undertaken any sort of management activity in this forest till date except periodical patrolling and mangrove seed collection in August–September every year.

The third site is again a riverside plantation (22°6′27″N, 88°55′23″E) along the Chargheri village raised by the local community under the leadership of a NGO named Purbasha Eco Helpline Society. The NGO is managing this forest since 1999 although it started promulgating the benefits of common property resource management way back in 1996 to the Chargheri villagers. Before 1999, the village embankment was reported to be severely eroded and breached at places leaving the inner settlement areas vulnerable to periodic inundations. The area between the LTL and embankment crest were almost devoid of any notable mangrove cover except few clusters of *Avicennia* varieties. This was also due to the unsustainable exploitation of mangrove woods and prawn-seed collection along the riverbanks by the locals that expedited the erosion. However, the same villagers now manage the plantations incessantly and prevent any type of illegal harvest under a co-management mechanism formulated by the NGO. The NGO officials and villagers, especially young school pass-outs and women, were accordingly accompanied and guided by a group of retired FD officials and civil servants, researchers and academicians from Kolkata-based higher education institutions. The villagers in all these years have regularly planted new propagules in zonal pattern, protected those through make-shift fences, created outlets to drain out hypersaline water, and reintroduced several endangered floral and faunal species (e.g. *Aegiceras corniculatum* and *Tachypleus gigas*) in the intertidal zones. The co-management mechanism ensures that the villagers would receive the prime share of revenues earned from the controlled extraction of NTFPs, sell of mangrove seedlings from the nurseries, apiculture activities through captive bee-boxes, and ecotourism facilities in return of their services.

All these sites can be studied together in a comparative manner since these forests are of relatively same stand age and maturity as well as possess similar ecological sensitivity due to their locations adjacent to the Sajnekhali Wildlife Sanctuary. Moreover, all three sites have more than 500 ha of mangroves (as per 2013), similar geo-climatic setting, same saline-alkali soils with high clay percentages, average soil pH range of 6.5–6.9, average water salinity of 9–11‰, and similar tidal amplitude (5.08 ± 0.30 m) and semi-diurnal periodicity. Another remarkable feature of not only these three sites but all of the village-fringe forests of Indian Sunderbans are that no thinning, pruning, and zone-wise logging activities had been legally conducted here since the last 30 years.

Ecological studies for assessing mangrove condition

Assessment of mangrove condition was carried out in all selected sites by using few well recognized ecological parameters of mangroves (Thornton and Johnstone 2015). In the forest areas of each site, four sample plots of 10 m × 10 m size were taken at random at a distance of 500 m from the HTL at the riverbank to represent the health of the innermost forest parts in utmost detail. These parts were preferred purposively as these reflect the most developed canopy structure and floral composition within the whole forest. The plots were placed distantly from one another in order to cover the total forest across width. All trees having more than 1.3 m breast height (> 3 m overall height) and falling within these plots were considered for these measurements (Brokaw and Thompson 2000). Subsequently, the girth at breast height (GBH) of every tree inside the plot was measured with a measuring tape for estimating basal area (BA). BA was then calculated by the following formula (Ravindranath et al. 2000):

$$BA = \sum (GBH)^2/4\pi$$

where, $\pi = 3.14$.

Assessment of canopy cover (CC) was done using the Line Transect Method taking ten transects of 30 m

length in each forest area. In every 5 m, CC was assessed on the basis of ocular estimation of plant canopy coverage in percentage of total area and then the average of these measurements was computed as below:

$$CC = \frac{\sum_{i=1}^{n} CC_i}{n}$$

where, n = Total number of measurements in a forest area; CC_i = Canopy cover in percentage in ith measurement; i = 1, 2, 3, …, n.

Plant species diversity index (PSDI) of the forest was estimated by calculating the diversity index (Shannon and Wiener 1963):

$$PSDI = -\sum_{i=1}^{m} p_i \times \ln p_i$$

where, $p_i = n_i/N$; n_i = Number of individuals of ith species within an area; N = Total number of all the individuals of all the species within an area; i = 1, 2, 3, …, m.

Finally, tree density (TD) of a forest area was estimated by measuring the number of trees per sample plot and then converting it in number of trees per unit area as below:

$$TD = \frac{\sum_{i=1}^{n} T_i}{\sum_{i=1}^{n} FA_i}$$

where, T_i = number of trees in ith sample plot; FA_i = Forest area of ith plot; i = 1, 2, …, n.

Number of eudominant species (E_D) was calculated for each site according to the Tischler's Scale, i.e. $10 \leq E_D \leq 100\%$ (Tischler 1949). Moreover, the Bray–Curtis Similarity Index in percentage was calculated using the ComEcoPaC calculator to determine the similarity of tree species composition in the studied sites (Bray and Curtis 1957; Drozd 2010).

There was a need to examine the nature of differences in mean values of the applied ecological indicators among sites (Datta and Deb 2017). For this purpose, one-way analysis of variance (ANOVA) was used and when ANOVA detected significant differences between sites, Bonferroni post hoc tests were carried out to analyze pair-wise differences among sites ($p < 0.05$).

Plot-wise species composition was also examined for each site in regard to mangrove seedlings (< 1 m in height) to assess the trends of newer plantations.

These seedlings were considered as the regeneration class 1 and subsequently the saplings (1–3 m in height) were termed as regeneration class 2. Accordingly, the growth rate of seedlings for each site with respect to saplings was estimated in an indirect way based on the survival rates of the former. The following formula was used for this purpose (Hastuti et al. 2013):

Growth of seedlings $(\%) =$
(Sapling abundance/Seedling abundance) $\times$ 100.

Geospatial analyses of forest cover dynamics

Three multi-temporal cloud-free satellite images (Landsat) covering whole or parts of Sunderbans Biosphere Reserve were downloaded from the freely available United States Geological Service's (USGS) Glovis (http://glovis.usgs.gov) web site on 2nd December 2014 for the present study. These orthorectified images (with UTM projection and WGS 84 datum) consist of Landsat Thematic Mapper (TM) data (Path 138, Row 45; dated 18th November 2003 and 30th November 2008) and Landsat 8 data (Path 138, Row 45; dated 13th November 2013). Being mostly of same season, these images possess lesser chances of having misclassification errors during spectral analysis of different land use/land cover (LULC) types (Rahdary et al. 2008; Tucker et al. 2004). A topographic map (79 C/4) from Survey of India (SOI) at a scale of 1:50,000 were used for further geo-referencing. Field investigations were conducted in between January–April 2015 through 300 Ground Control Points (GCPs) and 60 plots of different LULC classes and then applied for accuracy assessment of prepared LULC maps. Here, each of the study sites was allotted equal number of these verification plots through a stratified random sampling approach (Ellis et al. 2011).

Image processing procedure had been conducted using ERDAS IMAGINE 9.1 and ArcGIS 9.3 software. Areas of interest (AOI) covering the three study sites had been selected after necessary image rectifications. Supervised classification of all the images was conducted by applying the maximum likelihood algorithm (Settle and Briggs 1987). Altogether, 6 LULC classes were adopted for image classification based on the author's a priori knowledge and field

Table 1 Mean vegetation indicator values ($\pm$ SE) of three study sites (N = 4)

Vegetation indicator	Study site managed by		
	NGO-community	EDC	FD
Basal area (m^2 ha^{-1})	42.723 $\pm$ 1.507[A]	36.413 $\pm$ 2.934[A]	18.424 $\pm$ 2.856[B]
Canopy cover (%)	76.25 $\pm$ 2.39[A]	60.00 $\pm$ 4.08[B]	37.50 $\pm$ 4.79[C]
Plant species diversity index (Value)	2.502 $\pm$ 0.099[A]	2.604 $\pm$ 0.155[A]	1.951 $\pm$ 0.138[B]
Tree density (number of trees ha^{-1})	10,950.00 $\pm$ 602.08[A]	10,850.00 $\pm$ 440.64[A]	11,525.00 $\pm$ 972.43[A]
Eudominant species (number)	1.00 $\pm$ 0.41[A]	2.00 $\pm$ 0.25[A]	2.00 $\pm$ 0.29[A]

Different uppercase letters indicate significant differences among sites according to indicator-wise one-way ANOVA (Bonferroni post hoc test, $p < 0.05$)

experiences of the study area (Zhang et al. 2010). These LULC classes are dense mangrove, open mangrove, agricultural land, bare earth/mudflat, non agricultural land and waterbody. Following the classification, accuracy assessments had been performed by calculating overall classification accuracies (in percentage) and Kappa coefficients (k) for all image AOIs (Jia et al. 2014). LULC verification plots were physically surveyed in 2008 and 2013. Moreover, information on the land use patterns of these plots during 2003 was obtained by interviewing few elderly local villagers (> 50 years of age) identified as traditional forest dependents (e.g. fisherman, honey and wax collector, crab hunter etc.). In each site, ten such persons were selected with the help of local government officials, NGO representatives, and EDC members. Among these respondents, females were majority in the FD and NGO sites but slightly lesser in number in the EDC site. In general, preference was given to the selection of female respondents since they were the prime extractors of mangrove woods and NTFPs from the village-fringe mangroves. These persons were recognized as the key informants because of their inherited as well as acquired knowledge on mangrove terrain characteristics, resource dynamics, and socio-economic reliance of the neighbouring villages of this part of the Indian Sunderbans.

Evaluation of economic sustenance

Achieving environmentally resilient livelihood in terms of localized resources is an integral part of community based natural resource management. In this regard, a structured questionnaire was used to qualitatively score the major socio-economic and environmental services and products of the study sites by a five-point Likert scale. In each site, the same ten key informants mentioned in the previous section were then asked to score the actual as well as potential services and products based on their experiences of the utilization patterns of respective mangroves. For this purpose, 12 such mangrove uses were identified first through review of relevant literature and then divided accordingly in three subgroups, i.e. commercial, aesthetic and ecological for better understanding of the respondents (Datta et al. 2012).

Results

In order to obtain a better assessment of the status of mangroves in three study sites, ecological appraisals and schedule-based interviews had been conducted simultaneously in January, 2015. In addition, analyses of multi-temporal satellite data had been found to be beneficial in this context for mapping ecological dynamics and spatio-temporal changes of these sites over a period of 10 years under different management regimes.

Condition of mangroves

Among the three sites, stand-wise structural indicators of vegetation varied considerably during the assessment year (Table 1). The NGO plantation exhibited higher average values (42.793 m^2 ha^{-1} and 76.25% respectively) for BA and CC than the other sites denoting the existence of mature mangrove stands here. On the contrary, FD protected mangrove had the lowest values in this respect, i.e. 18.424 m^2 ha^{-1} and

37.50% respectively. However, one-way ANOVA showed that whereas NGO and EDC plantations had no mean difference of values, the FD protected mangrove, in turn, differed significantly from the former two sites regarding BA values ($p < 0.05$). In contrast, significant mean differences of CC values among all the three sites had been obtained indicating considerable variation in forest composition and growth. Regarding the PSDI values, a slightly different scenario had emerged as the EDC plantation had performed better with a value of 2.604. Conversely, the NGO plantation recorded a lower value of 2.502 denoting comparatively lesser diversity than the EDC site with respect to mangrove trees. However, the scenario changed completely for TD values as the FD protected mangrove had the highest density (11,525 trees ha^{-1}) followed by the NGO plantation (10,950 trees ha^{-1}). This apparent anomaly regarding the trends of indicator status could be explained with the fact that, in most instances, TD values could become higher in the areas with high number of younger trees but higher values of BA and CC were not possible to be found here. Thus, the FD protected mangrove was assessed to be having least number of healthy as well as mature trees in comparison to the other sites. Here, the tree stand seemed to be transforming into a mono-specific one, a fact also supported by the count of eudominant species.

The Bray–Curtis Similarity Index between the NGO and EDC plantations was 54.59 and between NGO and FD was 59.29 denoting a moderate overlapping pattern of species (Table 2). However, the EDC plantation, with a dominance of *Avicennia marina* and *Bruguiera gymnorhiza,* was found to be having the least similarity with any other site.

The status of mangrove seedlings had also been found to be markedly different among the three sites

Table 2 Percentage of similarity of mangrove tree community composition across study sites

Site managed by	NGO	EDC	FD
NGO	–	54.59	59.29
EDC	–	–	42.35
FD	–	–	–

Similarity was calculated using the Bray–Curtis Similarity Index

(Fig. 2). The NGO plantation had cumulatively higher species abundance (12) for seedlings in all the four surveyed plots than their counterparts in other sites, i.e. 11 in the EDC site and 7 in the FD site. In reality, the FD protected forest was found to be dominated by only two species of seedlings, viz. *Aegialites rotundifolia* and *Avicennia marina*. This finding also conformed to the earlier inferences regarding tree stands of this site. Furthermore, growth rates of seedlings were measured to have a better understanding of the management effectiveness of the studied sites (Fig. 3). Here, the NGO plantation had again performed more satisfactorily than the other sites with at least six species of mangroves recording 60% or higher growth rates. However, condition was not satisfactory in the FD site since most of the species did not record any amount of growth at all.

Spatio-temporal changes in LULC patterns

The three sites had experienced notable changes in their LULC patterns in-between 2003 and 2013. The NGO and EDC sites had recorded considerable increases in the amount of dense forests from 2008 to 2013 (Table 3). However, the FD protected mangroves had lost almost 5.37 ha (reduction of 6.20%) of dense mangroves from 2008 to 2013 indicating lesser success in forest protection. Moreover, total amount of forest cover, including both dense and open mangroves, had been found to be least here among all sites in all 3 years of evaluation. Even the amount of agricultural land had also reduced in the last 5 years in this site. Here, only the non agricultural land category had registered an astonishing growth (242.18%) from 2008 to 2013 revealing a trend of gradual proliferation of non agricultural activities like human settlements, built up areas, roads, and shrimp culture farms (Fig. 4). These activities had also spread to the other sites but in a comparatively lesser extent. Remarkably, land under the bare earth category had reduced in all sites in-between 2008 and 2013. While these reductions had primarily attributed to the growth of mangrove covered areas in the NGO and EDC sites, the non agricultural land category was its prime beneficiary for the FD site. In the NGO site, some of the bare earth/mudflat had also been converted to built up areas during the post-*Aila* reconstruction works. However, it should be noted in this context that the NGO only supervises the mangrove plantation along
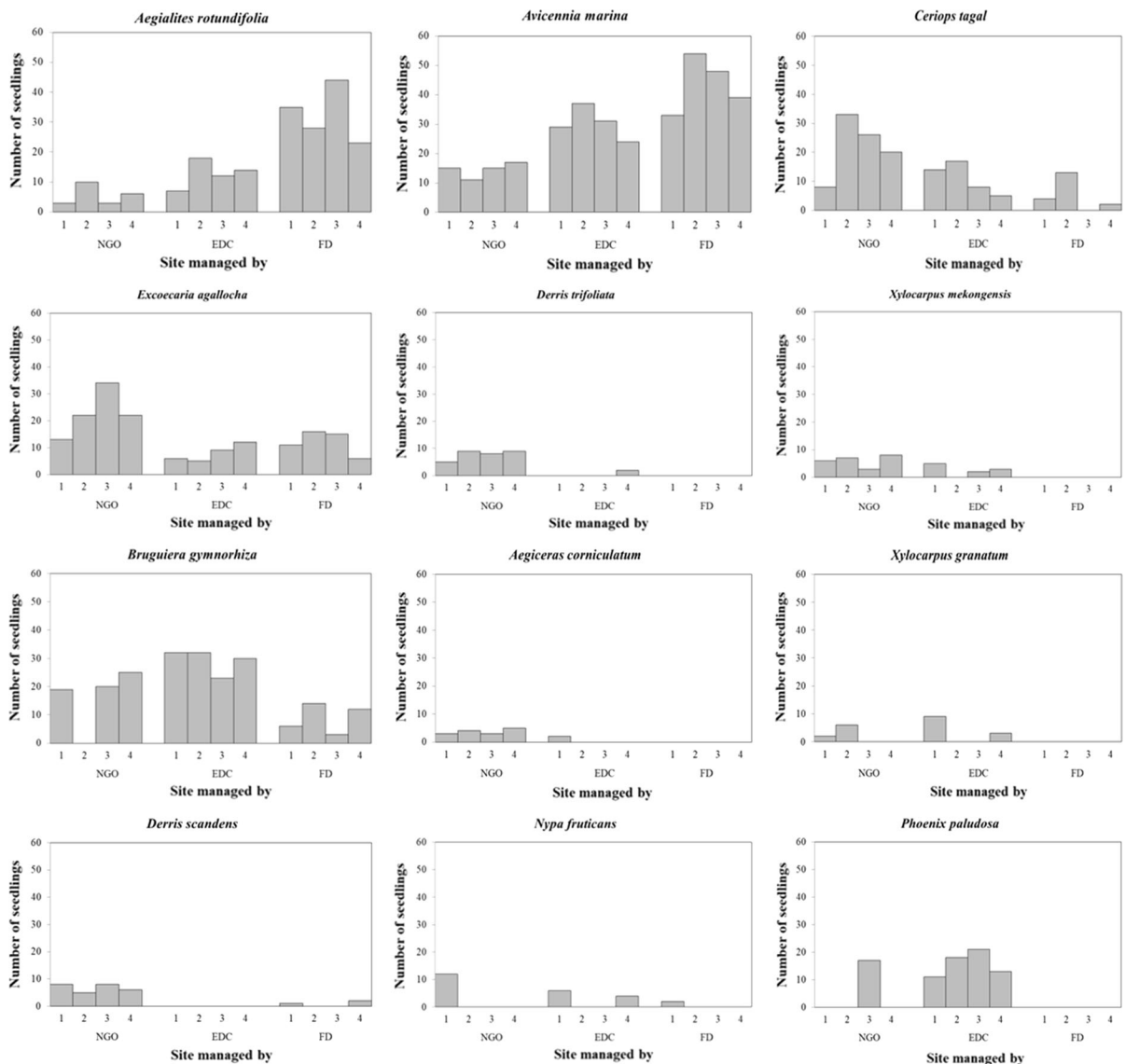
Fig. 2 Species composition of seedlings (< 1 m height) at study sites

with the adjoining mudflats but the administration of rest of the Chargheri village was out of its purview. The occurrence of human settlements in a dispersed manner with a temporary existence pattern was the salient feature of all the study sites. Many settlements shifted their locations in-between 2008 and 2013 chiefly under the impact of extreme quasi-natural hazards, like the cyclone *Aila*, devastating Sunderbans periodically (Datta and Deb 2012).

Assessments of accuracy of the produced LULC maps were also carried out in this regard. In general, the overall classification accuracy of each LULC map was found to be more than 74% on average (Table 4). Consequently, overall Kappa coefficients were also reported to be more than 0.65 indicating sufficient accuracy for the post classification comparison. Areas of confusion and misinterpretation were primarily identified to be roughly coinciding with the agricultural land, open mangrove, and bare earth classes.

Status of economic sustenance

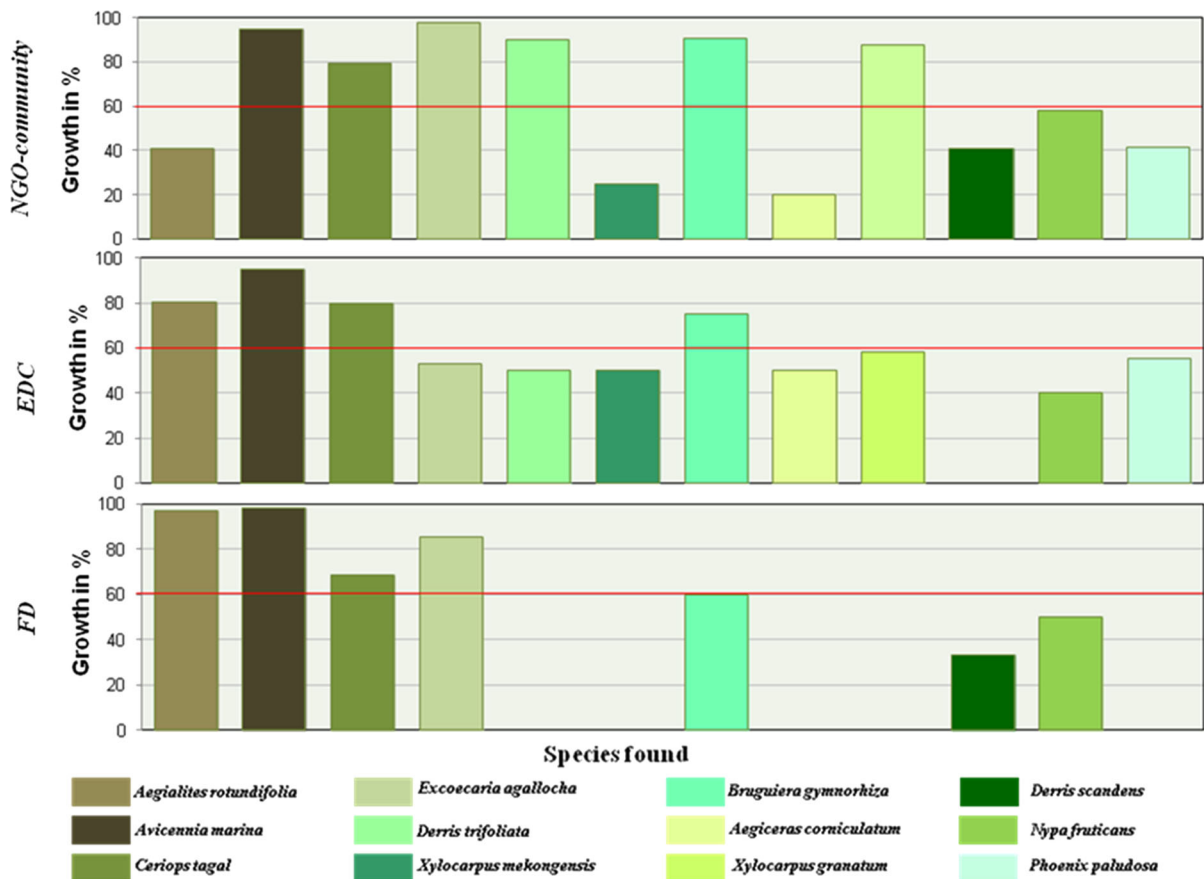Any participatory natural resource management initiative cannot become sustainable unless it ensures a

Fig. 3 Growth rate of seedlings (< 1 m height) across study sites

sustained flow of socio-economic products and ecosystem services (Sudtongkong and Webb 2008). In this study, all sites had been ranked by members of the user communities to analyze their respective livelihood supporting capacities (Fig. 5). Overall, the EDC site had obtained the highest average score (2.56) for livelihood support followed by the NGO site (2.42). The FD protected site had recorded a very low score (1.98) indicating an alarming status of economic productivity. However, the scenario for these sites altogether changed when scores of individual indicators had been studied. While the FD protected mangroves had been scored highly for its contributions in supplies of fuelwood (3.27), fodder (3.21), and construction materials (3.44), the site obtained lower scores for ecological and aesthetic products and services. Even the scores for NTFP based indicators like harvest of medicinal plants (1.30), honey and wax (1.15), tannin and dyes (1.10), and mangrove edibles

(2.12) of this site were also far from satisfactory. On the contrary, the NGO and EDC sites had scored highly regarding the supply of various NTFPs, ecological and aesthetic services. Thus, these sites were actually exhibiting greater potentials for sustainable ecosystem services than the FD site. For example, the NGO site had attained praiseworthy high scores for development of tourism activities (3.14) and land-scaping potentials (4.12) due to the earnest efforts of the particular NGO in establishing ecotourism facilities (e.g. eco-friendly accommodation options, nature walk, dissemination of local cultural heritages of folk songs, plays, and handicrafts etc.) in neighbouring villages thereby generating greater revenues for local populace. Similarly, resistance of riverbank erosion and storm protection functions had also achieved satisfactory scores in this site along with the EDC site. In reality, the indicators for which the FD site had recorded higher scores are directly related with small-

Table 3 Percentage area under different LULC categories for 2003, 2008 and 2013 for the study sites

LULC class	NGO-community					EDC					FD				
	2003	2008	Change (2003–2008)	2013	Change (2008–2013)	2003	2008	Change (2003–2008)	2013	Change (2008–2013)	2003	2008	Change (2003–2008)	2013	Change (2008–2013)
Dense mangrove	11.31	15.01	+ 32.70	18.99	+ 26.51	4.32	6.08	+ 40.66	30.86	+ 407.56	2.54	5.74	+ 126.29	5.39	− 6.20
Open mangrove	39.27	22.12	− 43.68	33.47	+ 51.29	12.66	23.10	+ 82.44	17.77	− 23.07	30.39	25.49	− 16.13	49.59	+ 94.53
Agricultural land	12.60	23.33	+ 85.10	23.60	+ 1.17	21.77	29.80	+ 36.93	12.17	− 59.16	17.45	23.31	+ 33.61	16.36	− 29.80
Bare earth/mudflat	17.64	19.18	+ 8.72	2.84	− 85.19	20.52	15.17	− 26.09	10.40	− 31.44	26.88	23.17	− 13.79	1.90	− 91.80
Non agricultural land	0.73	1.89	+ 158.10	3.14	+ 66.54	7.48	2.97	− 60.36	8.46	+ 185.20	1.66	1.93	+ 16.19	6.60	+ 242.18
Waterbody	18.43	18.46	+ 0.17	17.95	− 2.77	33.24	22.88	− 31.17	20.34	− 11.12	21.08	20.35	− 3.46	20.16	− 0.97

scale logging and selective removal of major timber yielding trees. Being a Biosphere Reserve, any type of logging is legally prohibited in Sunderbans and hence proliferation of these activities in a site protected by the government clearly manifests the failure in implementing necessary legal frameworks and management policies.

Discussion

The buffer forest areas of Indian Sunderbans are among the most fragile zones worldwide in terms of both environmental and anthropogenic disturbances (Biswas et al. 2009). Therefore, sustainable management of the natural environment is the immediate task for these areas and cannot be achieved without a holistic perspective towards development of local communities, resources and livelihood opportunities (DasGupta and Shaw 2013). Regarding the present study, it was observed that the different institutions performing management duties had exerted varied impacts on these sites resulting in wide-ranging forest structures and livelihood supporting capacities. Since all these mangroves had almost similar timeframes of initiation and environmental set-ups, their developmental trajectories could be related with the site-specific harvesting patterns and management efficiencies of different stakeholder institutions mentioned in this study. In this scenario, the prime inference could be drawn is that well-coordinated and inclusive management practices as well as controlled provisions of mangrove based diversified livelihood options were generally leading to healthy ecological composure of the forests and vice versa. The results of respondent appraisal and land use/land cover analysis actually supported and validated this inference. For instance, the FD protected site lagged behind in every aspect of ecological sustainability regarding biodiversity, tree growth and maturity from the NGO and EDC sites. In the absence of sufficient number of mature trees, the FD site was gradually becoming an open degraded one. These ecological findings were also confirmed by the higher rates of mangrove wood extractions reported in the respondent appraisal and reduction in the amount of dense mangrove covers (2008–2013) estimated from satellite imagery. Even some particular species of mangroves for which the Sunderbans is well known were conspicuously absent in this site, e.g.
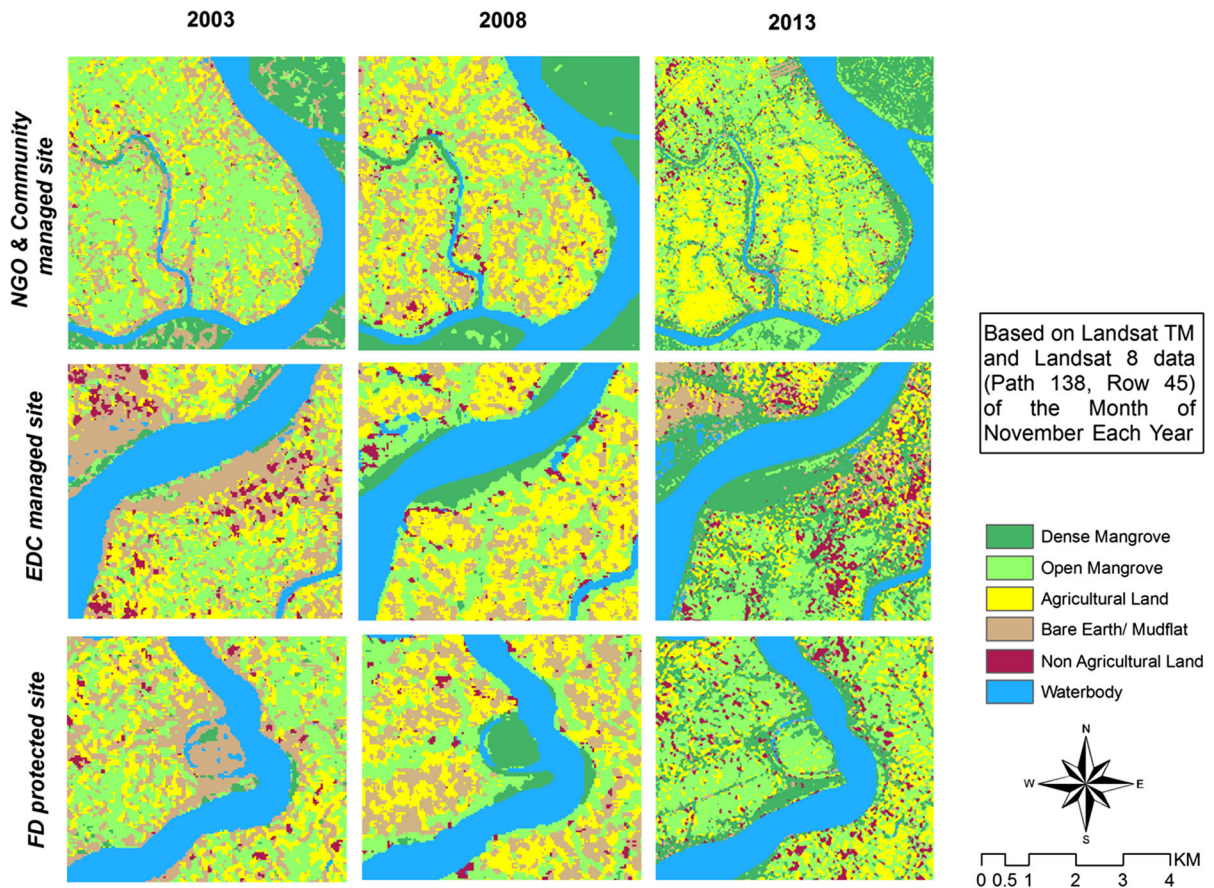
Fig. 4 Spatio-temporal changes in LULC patterns of the study sites from 2003 to 2013

Table 4 Accuracy assessment for supervised classification of multi-temporal Landsat images (AOI based) for the study sites

Each site was allotted 20 plots for ground truthing and comparison with reference data

Site managed by	Year	Overall classification accuracy (%)	Overall Kappa coefficient (*k*)
NGO-community	2003	80	0.76
	2008	85	0.81
	2013	90	0.87
EDC	2003	85	0.81
	2008	75	0.69
	2013	80	0.75
FD	2003	80	0.76
	2008	75	0.69
	2013	90	0.87

Phoenix paludosa, Xylocarpus granatum, Xylocarpus mekongensis, and *Aegiceras comiculatum.* In the absence of any effective protection and surveillance from the FD, the marginal and poor villagers illegally harvested these species in frequent manner as most of these were either timber yielding or suitable for producing NTFPs. The FD staff comprising Beat Officers and Forest Guards had been mostly found to be incompetent in performing their assigned duties in this difficult terrain. During fieldworks, it was found that many propagules of newly planted mangrove species were washed away by the high tides every day at both of the FD and EDC sites chiefly due to the utter negligence or faulty planting techniques adopted by
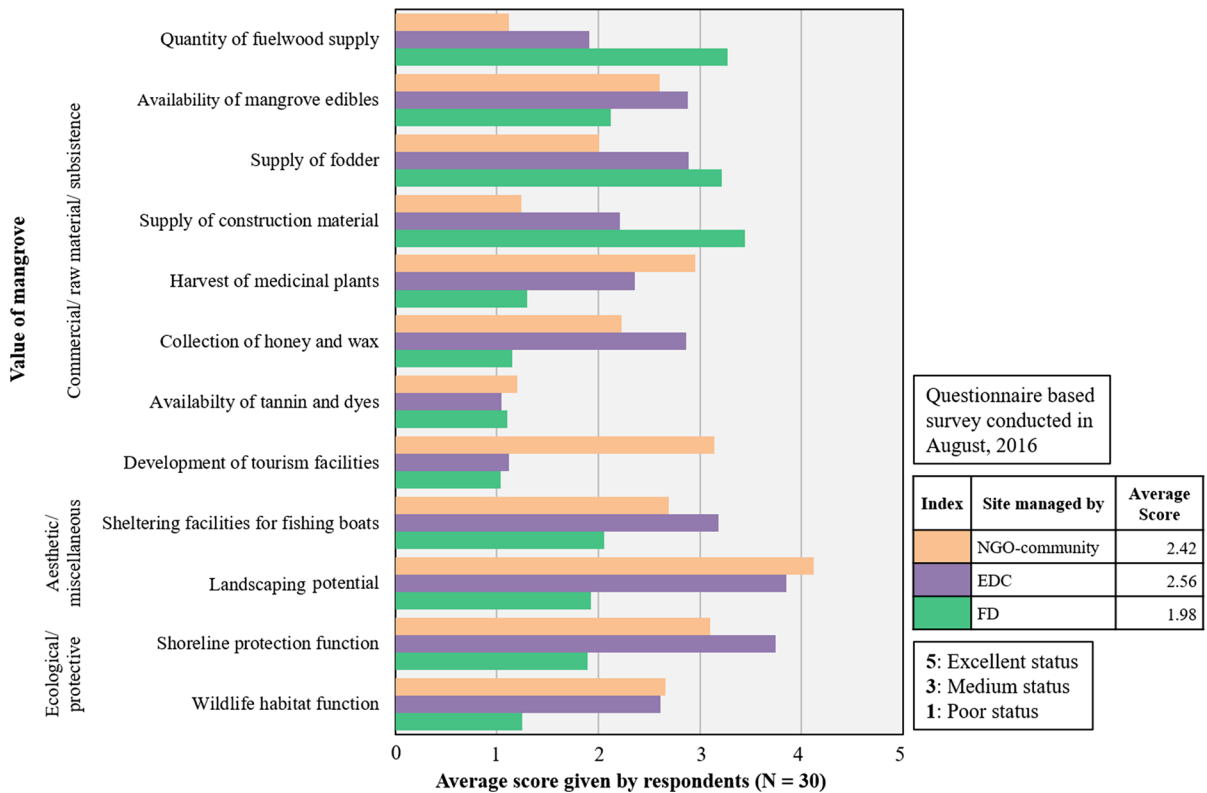
Fig. 5 Status of economic/environmental services obtained by villagers from the study sites

the FD staffs. Moreover, the lack of local people's legal access to and control of mangrove resources in this site had aggravated the degradation process. On the contrary, the NGO and EDC sites had succeeded in raising their forests more sustainably through active participation by the actual forest users. This finding was also supported by the fact that the diversity of newly planted saplings and seedlings were much higher particularly in the NGO site. In reality, the FD staffs generally preferred the planting of *Avicennia* species around islands (Datta 2013). This was due to comparatively easier means of collection of seeds of *Avicennia* along the riverbanks during the periods of germination rather than seeds of other mangrove species. Even this sort of mono-specific planting activity was not at all carried out in the FD site of the present study. Unlike the core forest areas of Sunderbans managed by the FD, these village-fringe sites were often becoming the products of utter neglect in terms of holistic management efficiency. What the FD officials were performing here could only be termed as blatant territorial jurisdiction and not sustainable

management. In general, the FD was immensely concerned towards conservation of the core areas of Sunderbans rather than managing these tiny buffer sites. Their negligence towards these village-fringe forests was also reflected in their lesser vigilance in the interiors of EDC managed mangroves. Accordingly, planted mangroves in the EDC sites were found to be harvested unlawfully much before the completion of their gestation periods in many instances. Subsequently, these forests will become less productive in terms of both biodiversity and livelihood in the imminent years. Only the NGO site had tried to address this issue by establishing a mangrove nursery. Whereas the NGO site had effectively checked the process of riverbank erosion, it had become a matter of concern for the FD site. This success of the NGO site can be attributed to the well-planned site-specific as well as zone-wise plantations of different mangrove species in consultation with local resource persons. Here, this plantation activity had suitably addressed the dual needs of NTFP generation in the inner forests and erosion resistance along the riverbanks. The NGO

had also taken few initiatives to collect honey from less hazardous captive bee boxes and cultivate valuable mangroves with medicinal qualities at Chargheri village. Thus, although the FD site had ranked higher by the local users regarding timber and fuelwood production, it can be safely stated that this was a rather short-term achievement. In the next few years, this site is surely going to experience acute dearth of most of the timber yielding and economically valuable species of mangroves if immediate corrective measure are not taken. Even this was also a matter of concern for the EDC site where new plantations were not as much enriched in biodiversity as the mature ones. Here, in-depth discussions with the local resource persons revealed that the bureaucratic attitudes of the executive members of EDC and their unwillingness to include the actual forest dependents comprising the economically marginal and lower caste people in decision making were hindering the entire management procedure in that site. Thus, the EDC and FD sites had actually evolved into sorts of efficient mechanisms of short-term resource exploitation instead of becoming examples of environmental stewardship here (Walters 2004). For example, the FD site had experienced an increase of open mangrove cover (primarily *Avicennia marina* and *Aegialites rotundifolia* stands) from 2008 to 2013 through mangrove colonization across the barren mudflats. However, the biodiversity status and forest structure of these new growths remained notably poor as revealed by the ecological assessments. In these circumstances, how many of these stands were capable of withstanding the high winds and sea surges of severe tropical cyclones? How much NTFPs could these stands supply sustainably in the long run? When could these stands attain maturity and ecological composure akin to the natural mangroves of core areas of Sunderbans? All these questions returned pessimistic answers. In 2009, the cyclone *Aila* actually caused immense destructions in the adjoining villages of FD and EDC sites but notably lesser damages in the NGO site. This could be considered as a direct impact of management efficiency and harvest intensity of respective sites (Paphavasit et al. 2008; Williams et al. 2007; Rahman and Rahman 2015). Thus, only performance of the NGO site was considerably satisfactory in terms of both ecological conservation and livelihood generation. It should be mentioned in this regard that the author found overwhelming plausibility of making

these sites as part of the global 'Reducing Emissions from Deforestation and Forest Degradations and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries' (REDD +) programme during the fieldworks. Becoming part of REDD + programme will probably ensure the sustained flow of funds necessary for raising and maintaining new plantations as well as initiating eco-friendly livelihood options like cultivation of medicinal plants, on-site processing units of honey and wax, ecotourism ventures etc. (Ravindranath et al. 2012). In reality, only sincere efforts from the upper tires of administrative hierarchy of both the State and the Country can bring these opportunities to the marginalized and poverty stricken populace of the Sunderbans. Moreover, there should be an urgent policy reversal regarding the orientation of planning and managing the village-fringe 'buffer' mangroves of Sunderbans at different ranks of Indian forest administrative hierarchy to appropriately address their management complexities. Unfortunately, no such notable initiative had been observed in this region till date. Similar inferences were made by Amarasinghe et al. (2002) on the brush park fishers who practiced mangrove silviculture in a Sri Lankan estuary by extracting mangrove twigs and branches to construct their brush parks and had contributed significantly towards mangrove conservation. However, centralized mangrove management schemes often advocate the externalization of this dependent populace from decision making processes.

Conclusions

Sustainable management of mangroves adjacent to the densely populated areas is a considerably difficult proposition and needs multidimensional intervention. Among all sites, only the NGO managed plantation of Chargheri had almost achieved that feat by engaging local stakeholders in decision making, planting, monitoring, and usufruct sharing processes. Their sincere efforts had also been reflected in establishing on-site processing facilities for some harvested NTFPs leading towards considerable value additions. Thus, it could be cited as a best practice as well as exemplary scenario of resilience for all community based endeavours of mangrove restoration in Indian

Sunderbans. The other two sites under investigation are, however, merely functioning as instances of short-term nature exploitations at present. At the most, these sites may be recognized for their efficient procedures of mangrove harvest and livelihood generation but these apparent achievements are purely of shorter durations as the natural milieu of these areas are deteriorating day by day in absence of appropriate management measures. In spite of being a forest of primary succession, the FD site failed to match the ecological vitality achieved by the mangroves of secondary regeneration at the NGO site. The secondary forest of EDC site performed moderately in overall consideration. In such sites, success will not be achieved by blatantly replicating the plans, activities and resource sharing formulae of the Chargheri initiative, rather by nurturing their own endeavours with similar spirit and purpose both for short and long-term dividends in the imminent years.

Overall, this paper attempted to explore the subtle but differential characteristics of the various mangrove management alternatives existing in this region. Both qualitative and quantitative assessment of forest health, planting trajectories, and ecosystem services and products had been conducted to obtain a holistic perspective of these management endeavours. Although an empirical methodology have been adopted here, emphasis was always on the nuanced understanding and recognition of the aspirations and perceptions of the local forest dependents through collaborative learning and sharing of their life experiences on these fragile mangroves and related livelihood strategies, However, the inferences made in the study could be more refined if suitable bio-indicators (especially based on micro and macro-fauna), total economic valuations, and soil–water parameters were applied for the evaluation process. Moreover, periodic monitoring and replication of similar exercises in the impending years will certainly enhance the knowledge domain of community based mangrove management in general and provide a positive impulse to the quest of saving these dwindling mangrove forests in particular.

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